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Research Department Report

A PRACTICAL STUDY OF A VIBRATION ISOLATED ROOM

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Summary

It is common practice within the BBC to support studios and similar rooms on 'anti-vibration' mountings (AVMs) in order to provide isolation from structure-borne sound. In practice these constructions do not usually achieve the designed resonant frequency. The isolation achieved is also rather doubtful. The Source Room of the Transmission Suite at Kingswood Warren, despite careful supervision of its construction, exhibited similar problems. This Report describes an investigation of the Source Room and its AVMs.

Index terms: *Acoustics; vibration isolation; rooms*

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1. INTRODUCTION

Studios and similar rooms are often constructed as a box which is linked to the main building structure only through resilient supports. The purpose of this is to isolate the room from structure-borne sound[1].

Tests in rooms built like this show that the resonant frequency is often indistinct and, if it can be measured, it is usually significantly higher than the design figure. It is also usually difficult to measure isolation between the supporting structure and the floated room.

At Kingswood Warren the Source Room of the newly built Transmission Suite is supported on rubber pads and has exhibited these problems. It was therefore decided that this room would be the subject of a detailed study.

2. THEORY OF VIBRATION ISOLATION

At its simplest, a floated room can be modelled as a mass on a spring with some damping. The response of the mass to excitation from the floor is shown in Fig. 1. At low frequency the mass simply moves with the excitation and there is zero isolation. At the resonant frequency, f, given by

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{M}}$$

where k is the spring stiffness and M is the mass, the mass moves more than the excitation. The height of the resonant peak is given by the 'Q factor' of the system. Above approximately $1.4f$ the mass moves increasingly less than the excitation. The response eventually decreases at 6 dB/octave.

For room isolation, the resonant frequency is usually chosen to be about 10 Hz so that there should be significant isolation at audio frequencies. If the resonant frequency is too low the occupants may become aware of room motion which would be rather unpleasant.

For many materials the stiffness measured under dynamic conditions differs from that measured using static loading. The dynamic stiffness is generally higher. It is, of course, appropriate to use the dynamic value in the above equation.

Various deviations from the ideal model will reduce the isolation achieved in practice. The room will not behave as a simple mass because of modes within its structure and because of non-vertical oscillation. The AVMs will not be perfect compliances. In addition, there may be unintentional bridges between the main structure and the floated room.

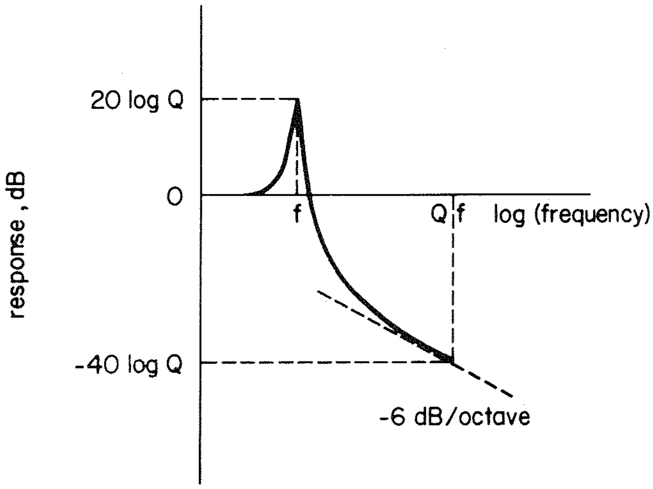


Fig. 1 - The vibration response of a mass on a damped spring.

3. THE TRANSMISSION SUITE SOURCE ROOM

3.1 Design of the AVM system

The Transmission Suite comprises two test rooms: Source and Receive. They are linked by an aperture in which test partitions can be built. Both rooms are independently floated so that the flanking path through the structure is not significant when sound reduction index measurements are made. A plan of the Transmission Suite is shown in Fig. 2.

The Source Room has a mass of 56100 kg. The internal dimensions are 5.9 m by 4.6 m by 3.7 m. The AVM system was designed to achieve a resonant frequency of around 7 Hz.

Each AVM consists of three layers of studded rubber carpet. The AVMs are spaced at approximately 1 m intervals around the perimeter of the room and under a central steel beam. Fig. 3 shows a view of the AVMs during construction of the Source Room.

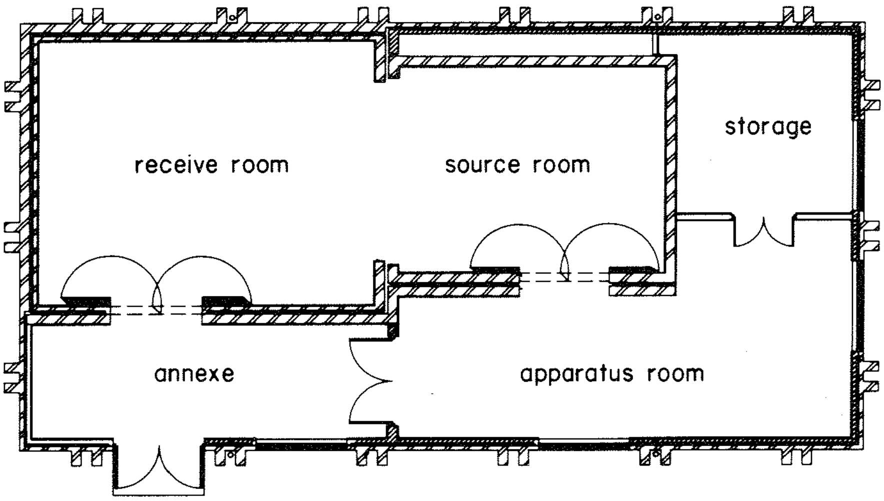


Fig. 2
A plan of the Transmission Suite.

The static stiffness of the rubber carpet was listed as 1.53×10^8 $Nm^{-1}m^{-2}$. An allowance of 1.5 for the ratio of dynamic to static stiffness was made. Therefore the dynamic stiffness per unit area, from the manufacturer's data, of the three-layer pad is

$$1/3 \times 1.5 \times 1.53 \times 10^8 \ Nm^{-1}m^{-2}$$
$$= 7.65 \times 10^7 \ Nm^{-1}m^{-2}.$$

The load per unit area of AVM is 42529 kg m^{-2}. This gives a theoretical resonant frequency of 6.7 Hz.

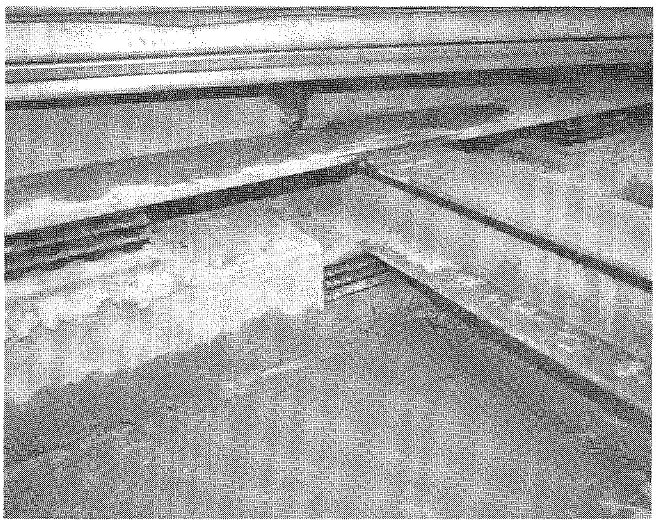


Fig. 3 - Photo of AVMs during construction of the Source Room.

3.2 Initial measurements

It soon became apparent that the Source Room did not have a clear resonant frequency. Fig. 4 shows a transfer function measured from the over-site concrete (accessible through holes in the source room floor) to the floor. Hammer blows on the carpet floor of the adjacent room provided the excitation. Note that the resonant peak is not clear. The region which resembles a fundamental resonance extends from 10 to 24 Hz. There is some evidence of isolation but this is questionable.

4. EXPERIMENTAL TECHNIQUES

Several methods of measuring resonant frequency were tried during this investigation.

The resonant frequency should be visible as the lowest frequency peak in the vibration spectrum of the room. The way this is measured is not critical. It is possible to use natural vibration, to excite the structure or to excite the room. One method which gives a clear peak is to excite the room with an electro-magnetic shaker, and to divide the vibration spectrum by the excitation noise spectrum.

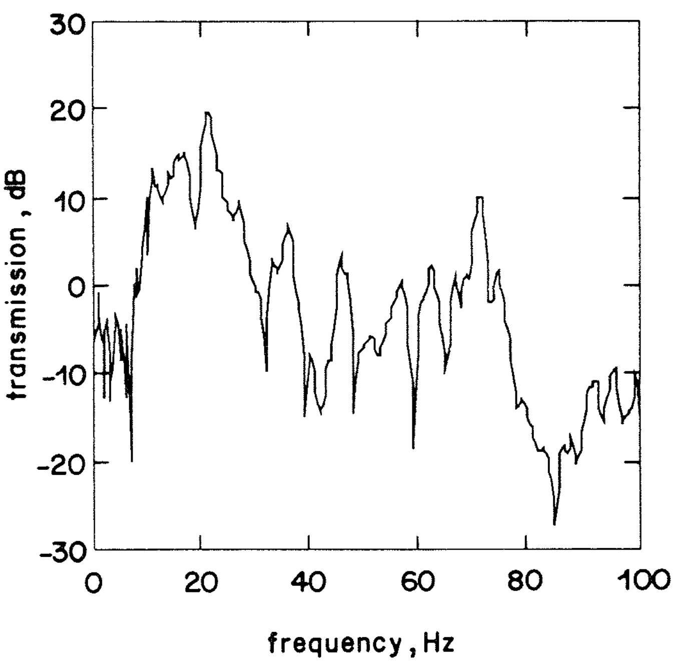


Fig. 4 - An early measurement of a transfer function in the Source Room.

For isolation measurements experimental technique is much more significant. A transfer function from the structure to the floated room is required. These measurements can conveniently be made using a two-channel, Fast Fourier Transform (FFT), spectrum analyser. The transfer function computed by an FFT analyser when using spectral averaging is usually $H_1(f)$ given by

$$H_1(f) = \frac{<A^*B>}{<A^*A>}$$

where A and B are respectively the input and output spectra, * denotes complex conjugation, and $<>$ denotes the mean value. $H_1(f)$ gives the best estimate of the response in the presence of noise in the output (channel B).

When calculating a transfer function on the basis of spectral averaging it is possible to calculate a measure of the 'goodness' of the result. This is called coherence. It is a function which measures on a scale from 0 to 1 the degree of linear relationship between the two signals at any given frequency.

Coherence is defined as

$$\gamma^2 = \frac{|<A^*B>|^2}{<A^*A><B^*B>}$$

If the coherence is low then H_1 may be quite different from the ratio of the two power spectra $|H(f)|^2$.

$$|H(f)|^2 = \frac{<B^*B>}{<A^*A>}$$

If unrelated noise is not the reason for low coherence then it is better to get the FFT analyser to compute the ratio of the power spectra $|H(f)|^2$ or 'B/A'. This is because, in the absence of noise, all of the 'B' spectrum is caused by the excitation even though there may be delays or non-linearities, and so 'B/A' is the most practically relevant measurement.

The most relevant excitation signal to use for measurements would be natural site vibration, but its amplitude is usually insufficient. The problem with artificial excitation of the structure is that the motions under the various room supports will generally differ in amplitude and phase. Although the simple vertical room motion will be excited, its relation to the overall motion of the structure will be rather confused. The effect of this is that different measurement positions and different excitations can give quite different results.

Accelerometers at the top and bottom of an AVM produce the most sensible looking results but these are not necessarily the most valid measure of overall isolation. For example, the vibration in the middle of a floor can be very significant, even though this may be the furthest point from an AVM.

Measurements made using hammer blows as the excitation and with the analyser triggered from each blow with an exponential window give good coherence (Fig. 5(a)). To obtain sufficient low-frequency energy it is necessary to strike a resilient material such as a few layers of packing foam (about 150 mm total depth). Alternatively a shaker driven by a very narrow band signal (e.g. warble tone) can give good coherence at very low frequencies (certainly 10 Hz).

Measurements made using a shaker driven by a noise signal do not give particularly good coherence. This is illustrated in Fig. 5(b). The difference can be attributed to the slow decay of structural vibration. With a noise signal the receive accelerometer has a constant background of vibration unrelated to the present excitation. Periodic noise with a rectangular window ought to be better in this respect since the decayed vibration will also be periodic. In practice it gives only a very slight improvement.

5. SMALL SCALE EXPERIMENTS

The first stage of the investigation consisted of experiments under controlled conditions at a small scale. A stack of paving slabs was supported on studs cut from rubber carpet of the type used to support the Source Room. The paving slabs were nominally 900 by 600 mm and each weighed 55 kg. Sand-filled bags were placed between the slabs. These prevented any rocking within the stack but did not add any unwanted compliance. Fig. 6 shows a typical set-up.

5.1 Static loading

Paving slabs were progressively stacked on top of four rubber studs (one under each corner). Dial gauges were positioned to measure the deflection at each corner during the loading. The four readings were used to calculate an average deflection.

The loading curve is shown on Fig. 7. After a small initial decrease in stiffness the curve is a good straight line. In the linear region, the stiffness per unit pad area was 2.4×10^8 Nm^{-1}m^{-2}.

The stiffness used in the design of the Source Room AVMs was calculated by dividing the manufacturer's figures for maximum load and maximum effective deflection. This figure was 1.5×10^8 Nm^{-1}m^{-2}.

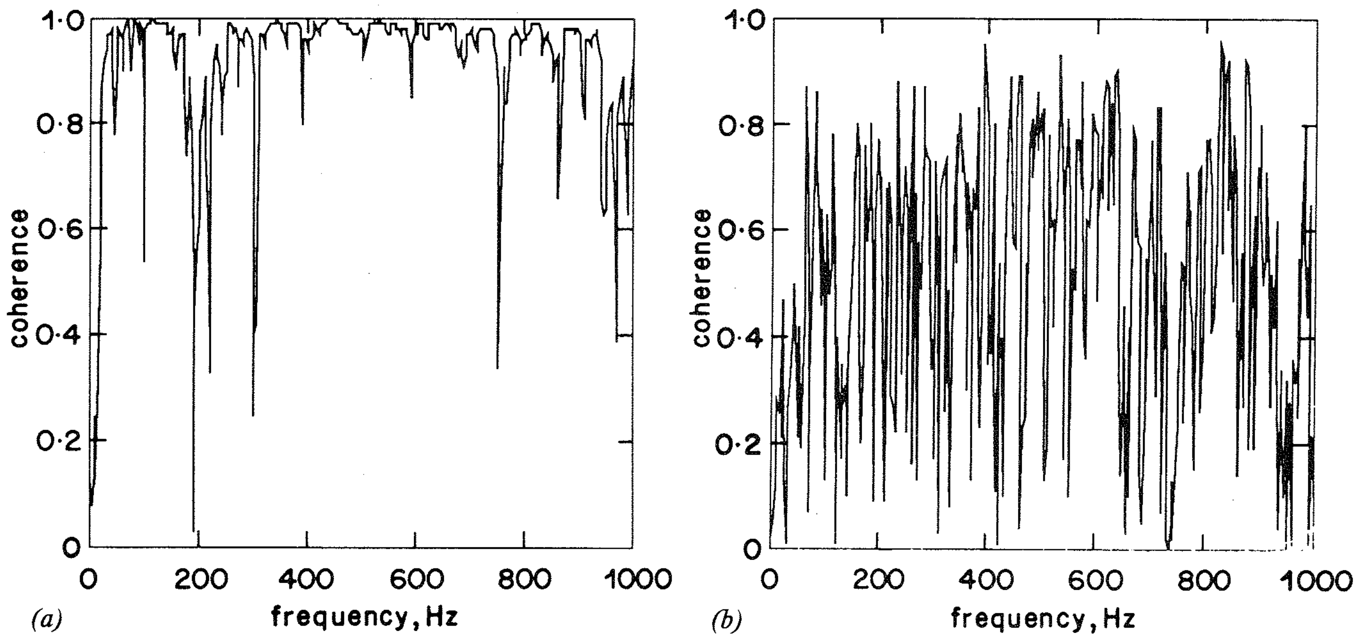


Fig. 5 - Comparison of coherence obtained with different excitations.
(a) Coherence obtained with hammer blows. *(b) Coherence obtained with an electromagnetic shaker.*

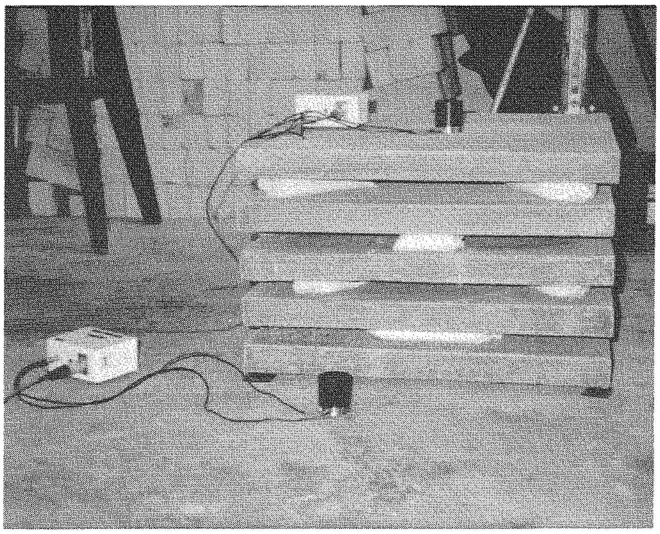


Fig. 6 - Photo of paving slab experiment.

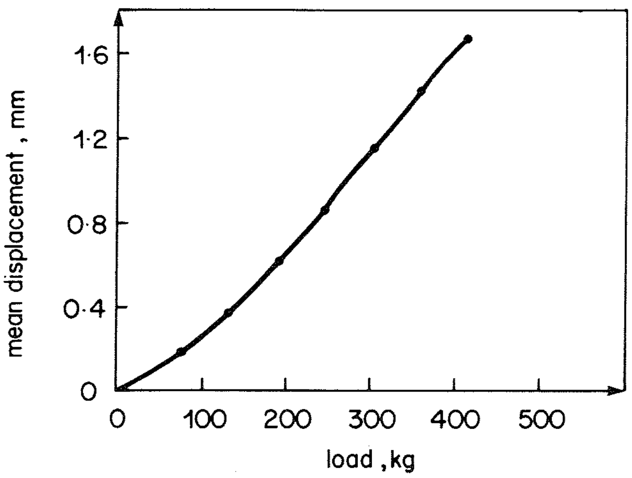


Fig. 7 - Loading curve for four rubber pads.

5.2 Dynamic stiffness

A stack of paving slabs was again supported by one rubber stud under each corner. A noise signal was fed to an electromagnetic shaker on top of the slabs and an accelerometer on the slabs was connected to a spectrum analyser which showed a clear peak at the resonant frequency.

The dynamic stiffness increased with load. The ratio of dynamic to static stiffness increased from 1.8 at 15% of maximum load to 2.6 at 83% of maximum load. It should be recalled that an allowance of only 1.5 was made in the design of the Source Room AVMs.

5.3 Resonant frequency with amplitude

It had been suggested that tests on floated rooms were measuring resonant frequencies higher than the design figure because the vibration amplitudes used for the tests were much higher than those which would be practically encountered.

A stack of four slabs was supported by one stud under each corner. This load is about 80% of the maximum for this type of rubber. The resonant frequency was measured as before. An attenuator was used to control the amplitude of the drive to the shaker. The resonant frequency was measured at successively smaller amplitudes until the limit of measurement was reached.

The amplitude of vibration was decreased from 1 mm to 1 μm. The lowest level used in this test was much less than that encountered in real installations.

As the amplitude was reduced the resonant frequency increased slightly. Over the range of 60 dB the resonant frequency increased by 8%. This effect is considered to be insignificant in comparison to other sources of 'error'.

5.4 Different pad distributions

An uneven distribution of the load of a room on its AVMs would be expected to affect the resonant frequency. This sort of unevenness could arise either from incorrect location of the AVMs or from unequal compression of the AVMs.

A few tests were made with a stack of four slabs on eight studs. The effect of an uneven distribution of load was to lower the resonant frequency. 1 mm spacers under alternate studs reduced the resonant frequency from 33 Hz to 31 Hz. It took a grossly uneven layout to lower the frequency more than 10%. With six studs at one end and two at the other the resonant frequency was reduced to 26 Hz.

5.5 Other vibration modes

So far only vertical motion has been considered. However, there are two other aspects of vibration to consider: non-vertical oscillation of the stack as a whole (e.g. rocking modes) and internal resonances (e.g. flexing of the slabs).

Modes were identified as follows. A shaker on the floor near a stack of five slabs was fed with noise. Accelerometers were positioned, for example, one at a corner and one in the middle of the top slab and a transfer function was measured. A peak in the spectrum was chosen which corresponded to anti-phase vibration at the two test positions. The amplitude and phase of the transfer function at this frequency was then noted at a grid of points across the slab keeping the position of the reference accelerometer fixed. For a well defined mode the phase difference is either close to zero or close to 180° so the amplitudes can be marked as either positive or negative. A contour plot is a convenient way to look at the results.

Rocking modes have frequencies slightly higher than the simple vertical resonance. (See Appendix 1.) In this case the vertical resonance was at 25.5 Hz and the first rocking mode appeared at 35 Hz. Fig. 8 shows the amplitude distribution of this rocking mode as a contour plot. The amplitudes shown are linear and on an arbitrary scale.

Internal resonant modes in this small scale model occurred at much higher frequencies. This would not be the case in a real room since its dimensions are much greater while the vertical resonant frequency is of a similar order. Fig. 9 shows a flexing mode of the top slab occurring at 379 Hz. The slab is bending about the perpendicular bisector of the longer sides.

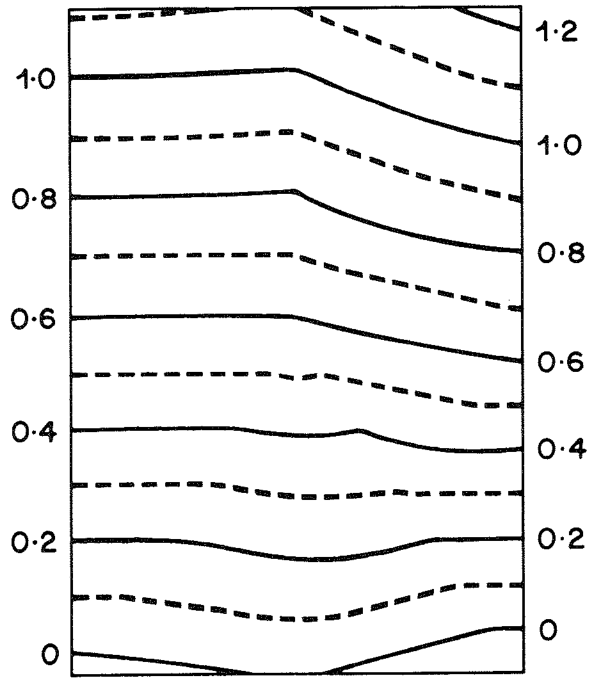


Fig. 8 - Contour plot of a rocking mode of the slabs at 35 Hz.

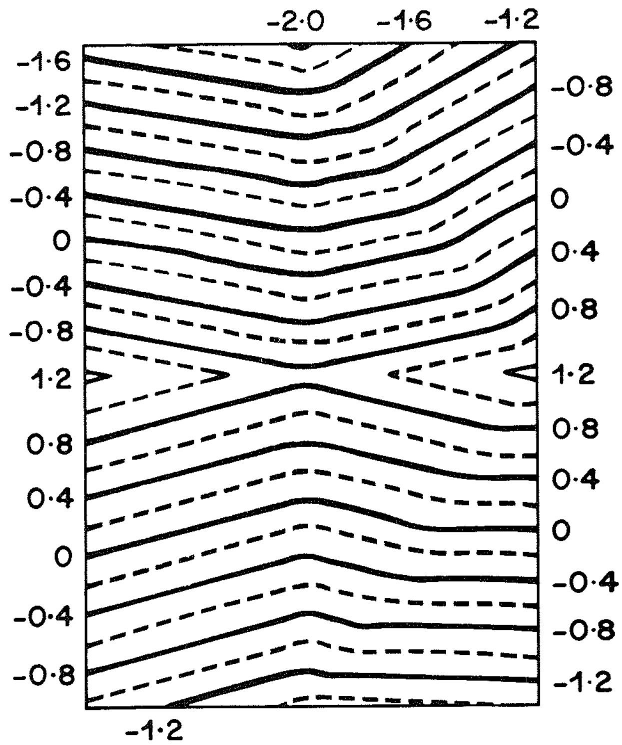


Fig. 9 - Contour plot of a flexing mode of the top slab at 379 Hz.

5.6 Vibration isolation

For these experiments a shaker was placed on the floor about 2 m distant from a stack of five slabs supported by a rubber stud under each corner. An accelerometer was positioned near the centre of the top slab and another was placed on the concrete floor next to the slabs. Both were connected to an FFT analyser. Transfer functions were recorded for various types of bridging between the floated stack and the floor.

The result for the unbridged case is shown in Fig. 10. The resemblance to the idealised curve of Fig. 1 should be noted. The resonant peak and the isolation above that frequency are clear. The isolation reaches a limit of about 12 dB at approximately twice the resonant frequency. Towards 100 Hz the isolation is destroyed by another resonance.

Structural bridging was represented by pushing a concrete block up against the side of the slabs near to a corner. It was necessary to force the block hard against the slab to produce an effect. Fig. 11 shows the resulting transfer function. The resonant frequency was increased and the isolation reduced. There is also another peak in the spectrum which indicates an additional mode of oscillation, although it is not strongly excited.

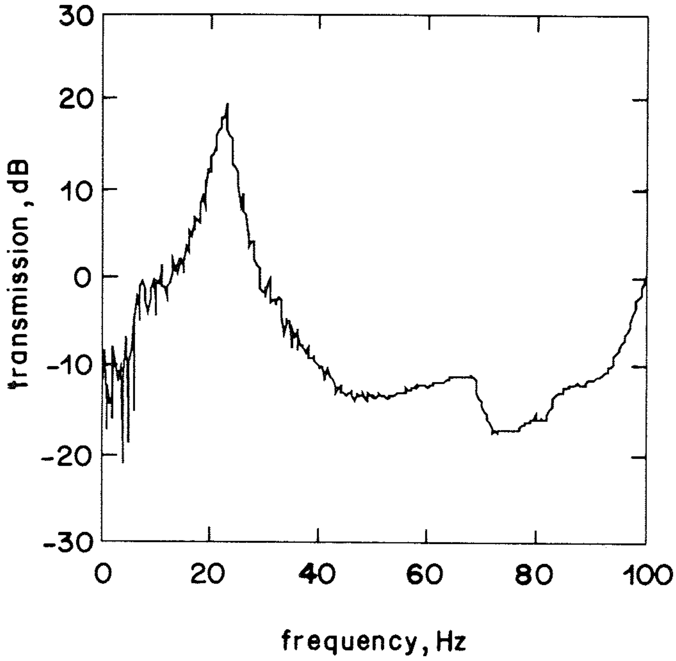


Fig. 10 - Transfer function for test slabs with no bridging.

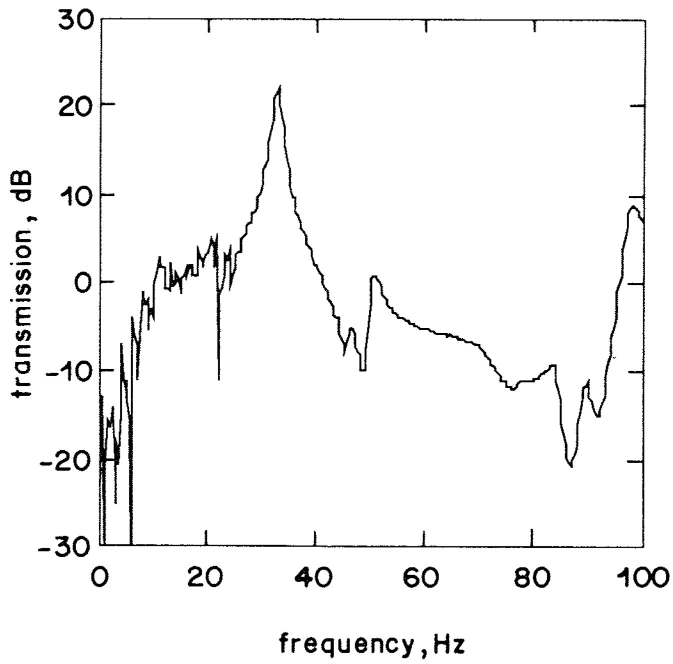


Fig. 11 - Transfer function for the test slabs with bridging by a concrete block.

6. EXPERIMENTS IN THE TRANSMISSION SUITE

6.1 Minor remedial work

Despite care with design details and supervision during construction it was felt that there might be some potential bridges between the main structure and the floated room. Remedial work was therefore carried out to remove potential bridging material.

As can be seen from the plan of the Transmission Suite, Fig. 3, the only double leaf walls of the Source Room are the stub walls around the test aperture and the wall with the door to the Apparatus Room. These cavities were filled with mineral wool (to prevent material falling down during construction and forming a bridge). For the most part they are inaccessible.

At the other room boundaries there is a cavity below floor level between adjacent floor slabs. The cavity was filled with mineral wool. The adjacent floor screed was designed to join the floated room via a fibreboard joint. This form of permanent 'flexible' shuttering has been considered a normal detail in floated constructions. It was noted, however, that the fibreboard would be a significant bridge and its removal was requested. It is unclear whether any modification was in fact made. On completion, however, the floor screed was still apparently bridging this gap. Therefore the edges of the screed were chipped away to expose the cavity, and the fibreboard and mineral wool were removed.

A mastic joint between the outer wall on the door side of the Source Room and the exposed inner wall at the Store Room end was removed. A fixing for the suspended ceiling of the Apparatus Room was removed from the exposed floated wall near the door to the Store Room.

None of this work made a clear difference to the resonant frequency of the room.

6.2 Static loading

In order to assess the static deflection properties of the Source Room supports, the room was gradually loaded by filling five interconnected 60 gallon water tanks. The room deflection was measured at four points. The objectives of the experiment were first to see if the static stiffness of the room was as it should be, and secondly to see if any sticking was evident during the downward motion.

The loading curves at the four test points initially showed varying amounts of sticking. After this they all followed straight lines with similar gradients. In the straight line region the average gradient corresponded to a total stiffness of 1.7×10^8 Nm^{-1}. If this stiffness were all attributed to the installed AVMs it would correspond to a static stiffness per unit area of a single layer of rubber carpet of 3.7×10^8 $Nm^{-1}m^{-2}$. This can be compared with the paving slab result of 2.4×10^8 $Nm^{-1}m^{-2}$.

For the initial friction-controlled motion the displacements at the extreme corners of the room were calculated on the assumption that the floor was rigid. These showed that one corner actually rose at first, indicating that the floor was pivoting about a point midway along the test aperture. There was also evidence of resistance to movement in the door wall.

6.3 Room mobility at very low frequency

Following the water tanks experiment, a further test was made of the mobility of the room in different places. This time the room was subjected to a dynamic force but at such a low frequency that it was effectively the static response of the room that was being tested. The frequency chosen was designed to be below that of any resonances but high enough for the shaker/accelerometer combination to be effective. The method was also used to investigate the effect of bridging.

A shaker operating at 5 Hz was placed on the Source Room roof and the amplitude of vibration at a grid of points across the floor was measured. A reference accelerometer close to the centre of the floor was used so that the phase of vibration could be checked. It was clear that the room was moving as a whole. The phase differences measured were at most one or two degrees.

Fig. 12 shows a contour plot of the vibration amplitude across the floor. The amplitude is on an arbitrary linear scale. Again there is a lack of mobility along the test aperture boundary, particularly in the middle. Also the door side moves less than the opposite side. This confirms the findings of the water tanks experiment.

A steel wedge inserted firmly between the floated room and the adjacent floor did not make a great difference. The wedged side moved slightly less than before but no bending about the wedge position was apparent.

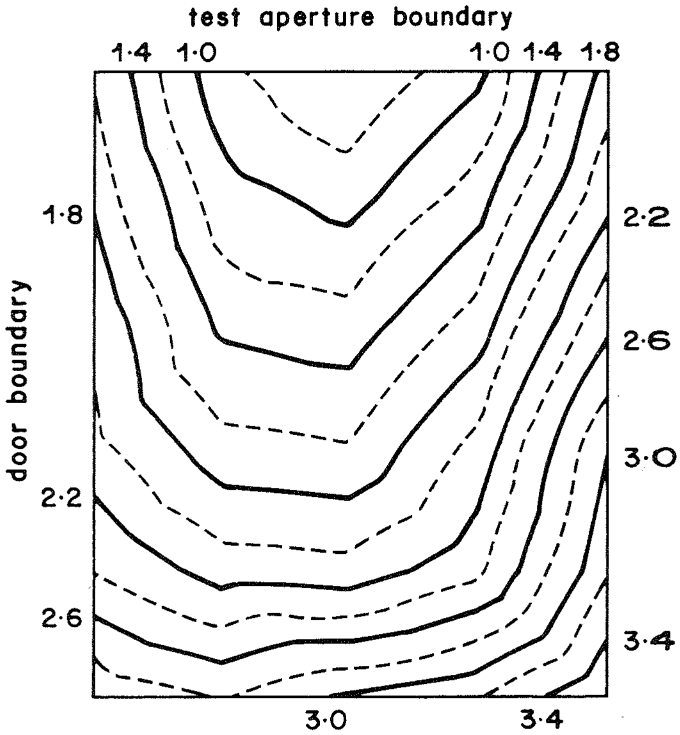


Fig. 12 - Contour plot of floor vibration amplitude at 5 Hz.

6.4 Further remedial work

The lack of mobility along the test aperture boundary was significant and so the cause was investigated. The test partition support consists of a steel beam resting on a concrete base. The beam is adjacent to but not in contact with the Source Room floor slab. Part of the concrete base is also adjacent to the floor slab. A sheet of fibreboard had been placed against the floor slab when the base was cast. This is illustrated in Fig. 13. It was found that concrete had soaked into the fibreboard and formed quite a firm bridge to the floated floor. This was obviously unsatisfactory so the edges of the base were removed

with a pneumatic hammer and recast using removable shuttering so that a clear gap was left.

Fig. 14 shows the 5 Hz mobility following this operation. The room motion is now much more

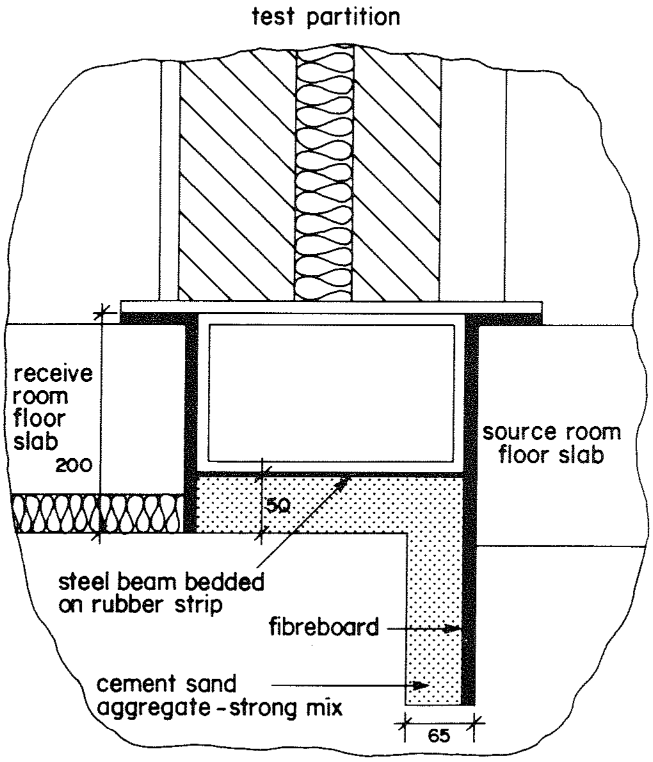


Fig. 13 - A section through the test partition support.

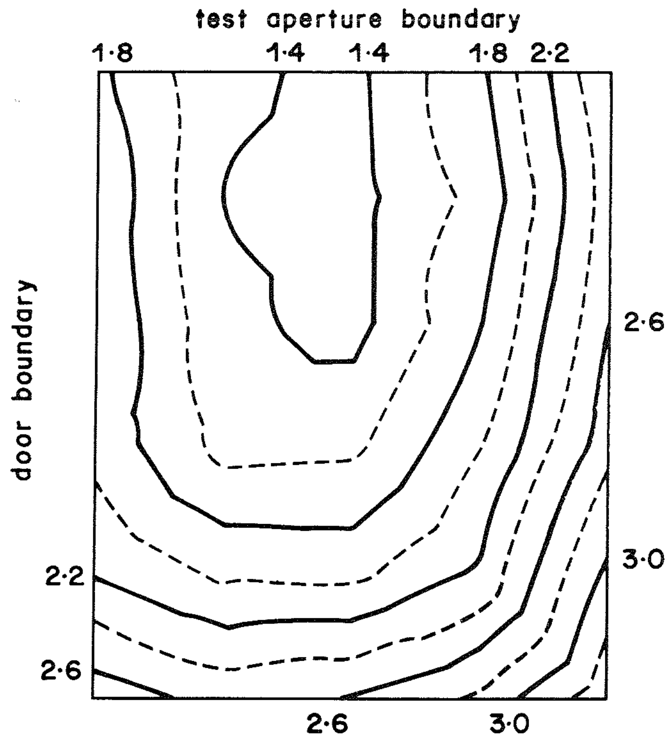


Fig. 14 - Contour plot of floor vibration amplitude at 5 Hz after remedial work.

uniform, although the test aperture side and the door side still move less than the others. It is possible that the reduced motion of the floor by the test aperture is due to the fact that it does not have a wall on it to transmit the force from the ceiling. A lack of symmetry between that side and the one opposite is to be expected.

6.5 Shear stiffness of the mineral wool used used in the wall cavities

The door wall and the stub walls around the test aperture have cavities which were filled with mineral wool, mainly to prevent building materials falling down and forming a bridge. This mineral wool was under slight compression and it was suspected that its shear stiffness might be significant.

The shear stiffness of the mineral wool was measured as follows. A brick-sized sample was cut and placed on the Source Room floor with a brick on top. An accelerometer was placed on the brick to record motion along its length and another was placed parallel to it on the floor. A resonant peak was clear in the transfer function. The measurement was made for one sample cut parallel to the surface markings of the mineral wool and one perpendicular.

The mean shear stiffness of the sample was calculated using the average of the two resonant frequencies. From this an estimate was made of the total shear stiffness of the installed mineral wool. The result (a dynamic stiffness) is 5.8×10^7 Nm^{-1}. This can be compared with the dynamic stiffness of the AVMs as predicted from paving slab measurements of 2.8×10^8 Nm^{-1}, that is, the mineral wool increases the stiffness by 20%.

6.6 Other modes of the Source Room

Modes of the room as a rigid whole, such as rocking, were investigated using shakers operating on the roof of the Source Room at opposite corners. A spectrum of the acceleration of the floor with in-phase excitation is shown in Fig. 15. The corresponding spectrum for anti-phase excitation is shown in Fig. 16. The accelerometer was positioned on the floor at a corner below one of the shakers.

The in-phase spectrum shows clearly a vertical resonance at 14.0 Hz. In the out of phase case two peaks are visible at 14.5 and 18.5 Hz respectively. With the accelerometer in the middle of a shorter side only the 14.5 Hz peak was present; in the centre of a longer side only the 18.5 Hz peak was present. The peaks can therefore be identified with rocking about the perpendicular bisectors of the sides.

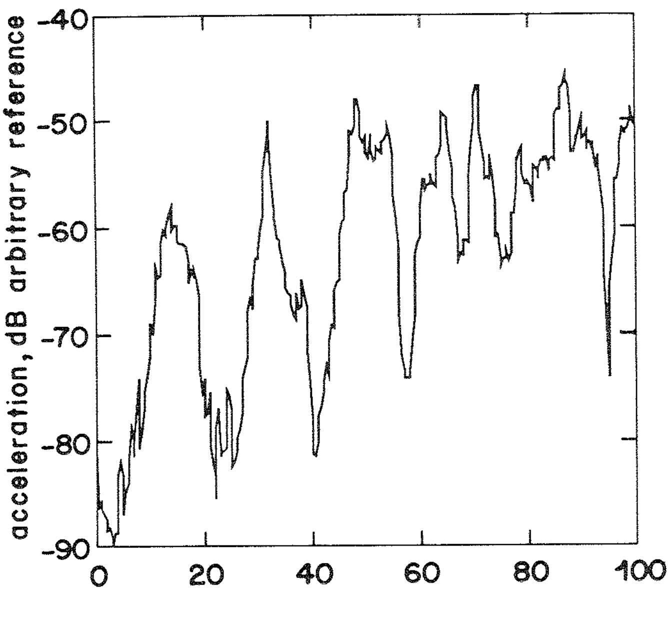


Fig. 15 - Vibration of floor for in-phase excitation.

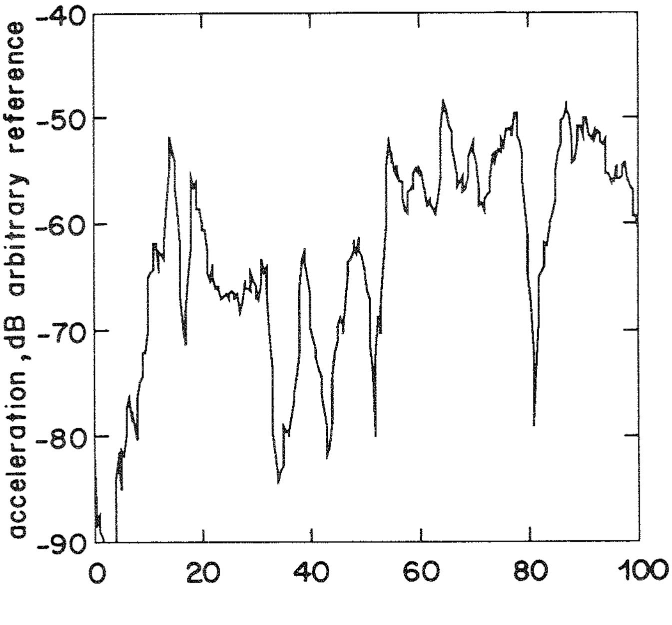


Fig. 16 - Vibration of floor for anti-phase excitation.

Note that the frequencies of the rocking modes are, as expected (see Appendix 1), slightly above that of simple vertical motion.

Modes of the structure of the room, such as flexing of the walls and floor, were also identified. Peaks from the spectrum measured on the floor with natural site vibration were chosen for further investigation. These resonances were often overwhelmed by others, but some frequencies could be found where the vibration was clearly in-phase or out-of-phase with a reference across the whole floor. One example was a small peak at 54.25 Hz. Fig. 17 shows the floor motion at this frequency.

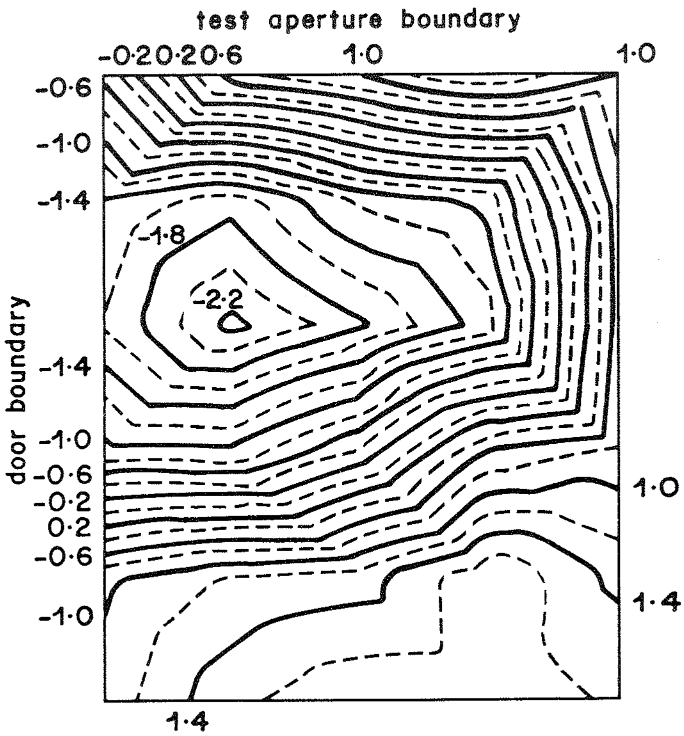


Fig. 17 - Contour plot of floor vibration amplitude at 54.25 Hz.

6.7 Vibration isolation

Rooms are floated to isolate them from structure-borne sound. This Report has concentrated on AVM stiffness and frequencies of various resonances. These are relevant to isolation but it must be stressed that a clear resonance at the correct frequency does not guarantee that useful isolation will be achieved. Other factors such as flanking paths, either structural bridging or air-borne, or additional resonances may destroy any isolation which would have been achieved. It is therefore important that isolation is measured directly.

Vibration isolation measurements were made with one accelerometer attached to the main building structure and another attached to the Source Room floor. At each position the two accelerometers were physically close. This is because if the floor were connected rigidly to the surrounding structure then nearby points on the floor and structure would have similar vibration levels because of their structural connection. Therefore any isolation measured between the structure and a nearby point on the floated room is a real effect of floating the room.

Three different positions and two types of excitation were used. Two positions were at floor access holes and the third was across the threshold of the doorway.

Natural site vibration was insufficient for measurement up to 1 kHz. The first type of excitation used was hammering on the carpeted floor of the apparatus room. An FFT analyser was triggered from each impulse, an exponential weighting window was used and 16 impulse spectra were averaged. The second excitation was an electromagnetic shaker in the Store Room driven by white noise band-limited to 1 kHz. The FFT analyser was used in free running mode with 50% overlap and a Hanning weighting window. 16 spectra were averaged. Both excitations comfortably exceeded the background noise except below about 20 Hz.

Narrow band 'B/A' transfer functions (B being the floated floor vibration) for the different cases are compared in Fig. 18. There is very little similarity. However, the measurements with hammer blows do generally show a significant isolation.

It appears that vibration isolation cannot be reliably measured. However, the validity of the results cannot be denied. If the site slab is vibrating with a certain amplitude and the floor above is vibrating 10 dB less then this is an improvement over what would happen if the floor were rigidly connected to the site slab. (Assuming, of course, that the effective mass of the foundation is much greater than that of the floated room.)

7. DISCUSSION OF RESULTS

The rubber pads used in the Transmission Suite Source Room do not approach their specification very closely, particularly with regard to the ratio of dynamic to static stiffness. The experiment with the paving slabs gave a static stiffness 1.6 times the figure used in the design. The dynamic stiffness was 2.7 times greater than the figure used in the design. This gives an expected resonant frequency of 11 Hz instead of the design figure of 7 Hz.

If the mineral wool in the wall cavities were all in shear, its stiffness would be about one fifth that of the installed AVMs. This further increases the expected resonant frequency to 12.5 Hz.

The initial resonant frequency of the Source Room, although not well defined, appeared to be around 16 Hz. Since the remedial work (particularly removing the fibreboard joint along the test aperture boundary) the resonant frequency is clearer and is now around 14 Hz.

The remaining discrepancy is probably due to additional stiffness resulting from minor structural bridging. The loading experiment with the water tanks did indicate that the apparent stiffness of the installed mountings was greater than was expected on the basis of the paving slab experiment.

8. CONCLUSIONS

8.1 The Transmission Suite Source Room

A significant structural bridge had been formed by a cement-soaked fibreboard joint along the test aperture boundary. After this was removed, tests on the freeness of the room indicated that all parts moved freely, although with more resistance where wall cavities were filled with mineral wool. In addition, it was found that even the strong bridging action of a steel wedge inserted very firmly between the floated room and an adjacent floor did not have a great effect. Experiments with the stack of paving slabs have also shown that it takes a firm bridge to make a significant difference and, even then, the qualitative behaviour of the system remains similar.

The conclusion is that minor bridging is unlikely to be a problem in floated rooms, provided there are no gross constructional defects.

Following the removal of structural bridging, the resonant frequency was about 14 Hz. This is about twice the design figure. The result is almost explained by the facts that (a) the dynamic stiffness of the AVMs is nearly three times the figure used by the designers and (b) the mineral wool used in wall cavities adds 20% more stiffness. The resonant frequency predicted on this basis is 12.5 Hz. The remaining discrepancy may be attributed to minor structural bridging.

In large structures, both non-vertical motions and internal flexing modes begin to occur at comparatively low frequency. These additional resonances reduce the vibration isolation that can be achieved.

The results from vibration isolation measurements vary a great deal depending on how they are made. The fact that the foundation slab and the floated room do not behave as ideal masses accounts for the erratic nature of these measurements. A vibration isolation measurement is only valid for the particular positions and excitation used. It is not sensible to compare results from

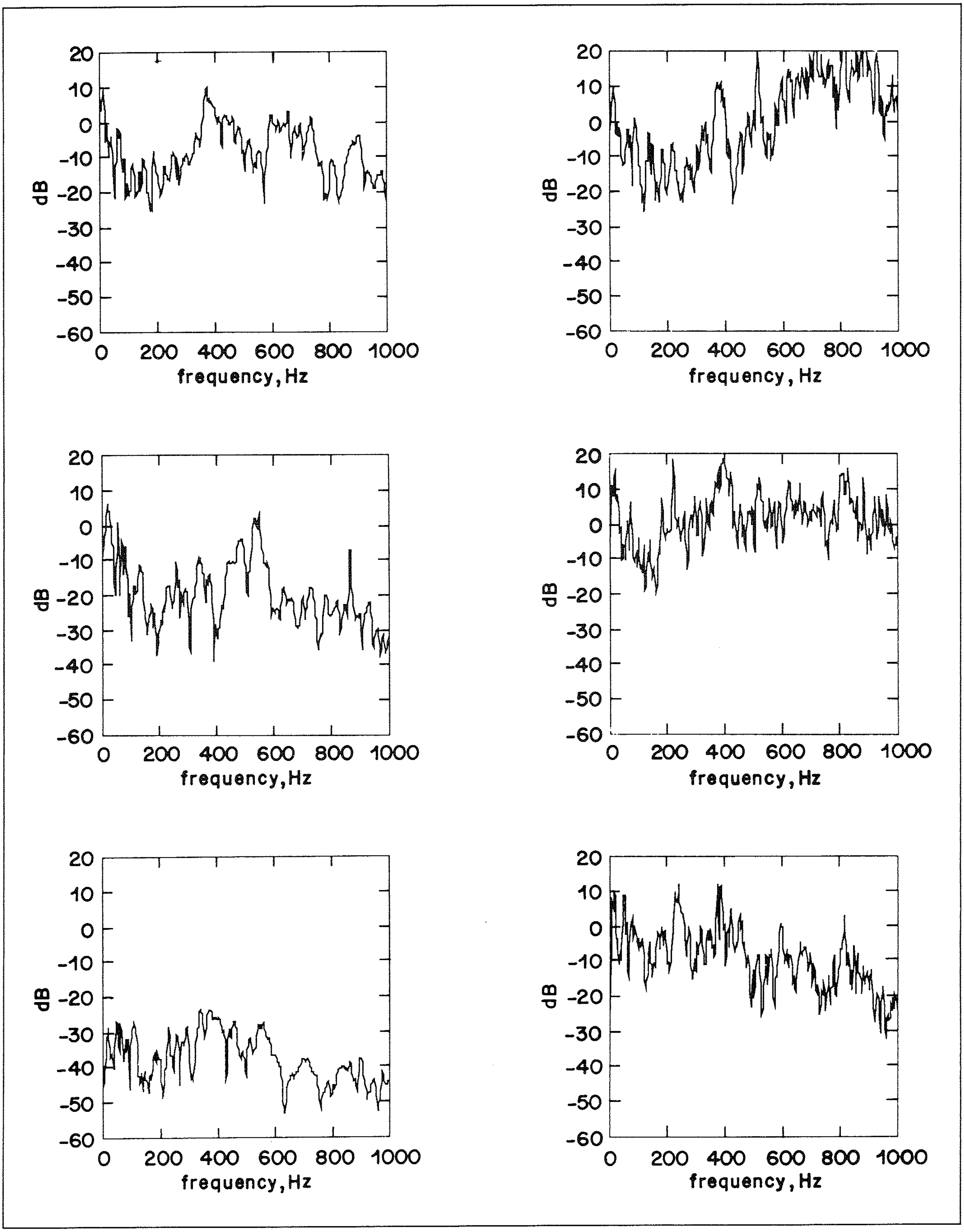


Fig. 18 - Transfer functions from main building structure to Source Room.

one building to another, except in a very qualitative way.

Floating the room does seem to have provided a significant degree of isolation from structure-borne sound, particularly impacts. In the case of impacts, the isolation achieved is of the order of 20 dB.

8.2 Experimental techniques

Resonant frequency can be measured consistently in several ways. It should be measured at two or three positions.

The freeness of a floated room can be measured by applying a low frequency sinusoidal excitation and recording the vibration level across a grid of points.

To characterise a resonance, the vibration should be measured across a grid of points and the phase compared with a reference position.

Isolation measurements should be treated with extreme caution. Comparative judgements should be made only on the basis of similar experimental technique and measurements at many positions.

9. RECOMMENDATIONS

If rubber AVMs are used to isolate a room, then the design should be based on an accurate assessment of the dynamic stiffness of the AVM. Manufacturer's or distributor's figures may be unreliable. This is not a criticism of rubber AVMs, as allowances can be made at the design stage. Other work has shown that alternative forms of AVM have significant disadvantages[2].

Where floated rooms are constructed it is highly desirable that a clear and accessible cavity is left around all room boundaries to ensure that structural bridging does not occur. Permanent shuttering in the form of fibreboard should not be used.

10. REFERENCES

1. WALKER, R. and MATHERS, C.D. 1989. The control of the audible effects of ground vibrations in building structures. BBC Research Department Report No. BBC RD 1989/2.

2. MATHERS, C.D. and WALKER, R. 1989. Some properties of antivibration mounts used in building isolation. BBC Research Department Report No. 1989/3.

APPENDIX 1

Rocking Modes

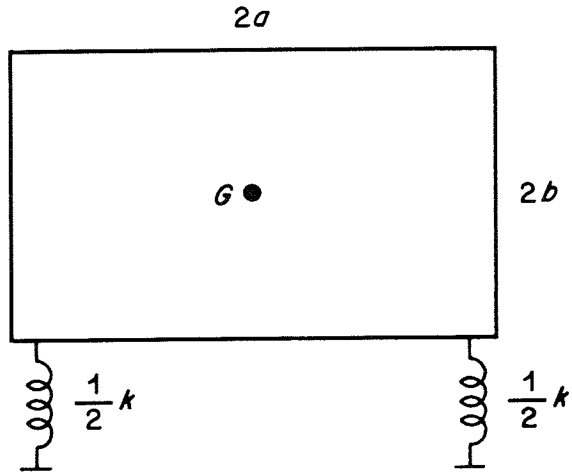
In this Appendix the resonant frequency of rocking is calculated for an idealised structure supported along two edges. The results are intended to be indicative only. A more even AVM layout would give a slightly different result.

In each case the total AVM stiffness is k and the total mass M. Therefore the vertical resonant frequency would be

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{M}}$$

The first case considered is free rocking of the room about its centre of mass (Fig. A1).

Fig. A1



For a small angle of rotation θ

$$I_G\ddot{\theta} = -2 \times a \times a\,\theta \times \frac{k}{2}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{a^2k}{I_G}}$$

For a solid block

$$I_G = \frac{1}{3}\ M(a^2+b^2)$$

$$f = \frac{1}{2\pi}\sqrt{\frac{3a^2}{(a^2+b^2)}\ \frac{k}{M}}$$

For a thin shell

$$I_G = \frac{1}{3}\ M(a+b)^2$$

$$f = \frac{1}{2\pi}\sqrt{\frac{3a^2}{(a+b)^2}\ \frac{k}{M}}$$

So typically the frequency will be slightly higher than that of the vertical resonance.

The second case to consider is when the room pivots about one edge. This might result from serious bridging (Fig. A2).

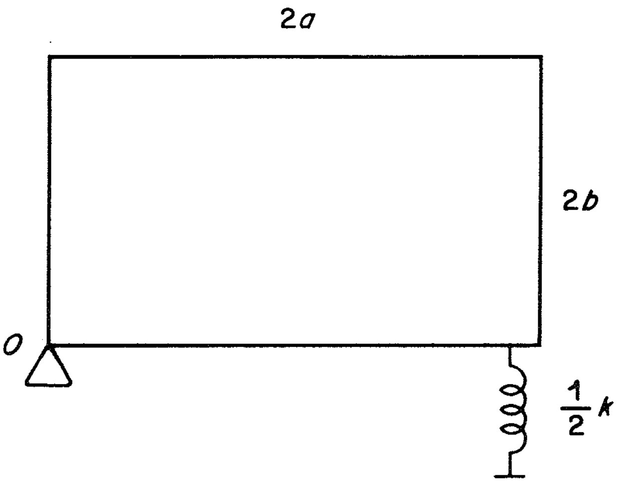


Fig. A2

Again for a small angle of rotation θ

$$I_o\ddot{\theta} = -2a \times 2a\,\theta \times \frac{k}{2}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{2a^2k}{I_0}}$$

For a solid block

$$I_o = \frac{4}{3}\ M(a^2+b^2)$$

$$f = \frac{1}{2\pi}\sqrt{\frac{3a^2}{2(a^2+b^2)}\ \frac{k}{M}}$$

For a thin shell

$$I_o = \frac{2}{3}\ M(a^2+ab+b^2)$$

$$f = \frac{1}{2\pi}\sqrt{\frac{3a^2}{(a^2+ab+b^2)}\ \frac{k}{M}}$$

Again, in both cases, the frequency would usually be slightly higher than that of the vertical resonance.

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